

Charge Gain

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Executive Summary

Noble element detectors benefit from high charge and light yields to enable detection of low-energy and rare signatures in searches for Dark Matter, neutrinoless double-beta decay, and measurements of neutrino interactions. Often, very low energy signatures require additional signal amplification in the form of charge gain, typically achieved in the gaseous phase of argon and xenon detectors. Multiple innovative methods are being developed to either enhance the capabilities of charge amplification in gaseous detectors or enable amplification directly in the liquid phase. Active R&D efforts on this front are described below.

[1] Electron multiplication in liquid argon TPC detectors: Enabling charge amplification in liquid argon would expand the physics reach of liquid argon detectors reducing thresholds to < 100 keV in energy and opening up new areas of research in processes such as Dark Matter and CE ν NS searches. Achieving charge amplification in liquid is significantly more challenging than gas due to the denser medium and higher electric field thus required. Past work on this idea [1A-4A] while promising, has not yet reached a level of maturity necessary to enable the technological advances needed for physics measurements. Benefits of direct amplification in liquid are a potentially improved detector stability (due to the lack of a gas-liquid surface) and detector scalability. Active R&D through the LArCADE program is exploring this possibility through the implementation of strong local electric fields with tip-arrays instrumented at the TPC's anode readout.

[2] Scintillating and Quenched Gas Mixtures for HPGTPCs: While there is a rich history of R&D in gaseous electronics much remains to be understood and optimized at high pressures and large scales sought by experiments. The realization of a stable, VUV-quenched gain, scintillation-capable, 10-15 bar TPC remains elusive. Two main approaches are pursued to enable these objectives, distinguished by their emission wavelength range: infra-red and Near-UV or visible readout. An ongoing program of R&D at the University of Texas at Arlington in collaboration with Santiago and Coimbra Universities in Europe aims to systematically map the space of scintillating gas mixtures of argon with admixtures of xenon, nitrogen, hydrocarbons and fluorinated compounds. The potential of new 'ad hoc' structures for pure and low-quenched gasses impacts the development of new ideas too, for instance in ND-GAr (DUNE) where Ar-CF₄ is being considered as a scintillating gas for providing the start time (T_0) [1B]. In such a case, the screening of the secondary scintillation impinging onto the photosensor plane might be critical, something that a GEM (conveniently optimized) can provide. Further,

independent measurements and calculations also show, on paper, that stable scintillation on very thick structures (5-10mm thick) is likely to be possible in liquid phase [2B-5B].

We advocate here that fundamental studies of scintillating gas mixtures is an area that should be given increasing attention in the US / World program, during the 2021 Snowmass period.

[3] Search for Low Mass WIMPs with Spherical Proportional Counters: The NEWS-G collaboration [1C,2C] searches for low-mass WIMP-like particles using spherical proportional counters (SPCs) filled with gasses such as neon, methane, and helium. The detector consists of a metallic spherical shell, held at ground potential. As the electrons approach within approximately 1 mm of the sensor, the magnitude of the electric field becomes sufficient for the production of secondary ionization. The high gain and low noise configuration allows for the detection of single-electron, enabling energy thresholds in the 10's of eV. The replacement of the C10100 140-cm SPC in the NEWS-G shield at SNOLAB, with a higher radio-purity electroformed copper SPC, will effectively unlock the full scientific potential of the NEWS-G experiment at SNOLAB and will allow the exploration of new dark matter interaction parameter space. Prospects exist for directional dark matter searches using SPC filled with low pressure gasses and a multichannel readout.

Instrumentation requirements to achieve physics goals (list)

- [1] local electric fields of 10^6 V/cm which are stable in time for charge amplification.
- [1] 10s-100s of nm scale localized geometries for charge amplification.
- [2] Ability to detect infra-red components of scintillation emission.
- [1,2] Well understood dopant environment.
- [2,3] Low-radioactivity environment for materials in detector.
- [3] Sensors allowing for single-electron threshold in large volume SPCs

Significant instrumentation challenges (list)

- [1,2,3] Strong understanding of detector microphysics (and impact of geometry or dopants)
- [1] Ability to sustain 10^6 V/cm electric fields and produce adequate geometries for charge amplification.
- [2] Ability to detect scintillation light at Infra-Red wavelengths.
- [2,3] Maintaining a low-radioactivity detector environment.
- [1,2,3] Backgrounds at low energy are not well understood
- [1,2,3] Ionization yield of electrons and ions at very low energy are challenging to measure

Relevant physics areas (e.g., low-mass DM, solar neutrino oscillations, CEvNS)

- Neutrino physics: CEvNS, supernova, atmospheric neutrino, neutrinoless double-beta decay interactions. Measurements of cross-sections and neutrino oscillations, as well as enhanced rare-interactions searches.

- Direct dark matter detection

Relevant cross-connections (e.g., other topical groups, other white papers)

(CF1) Dark Matter: Particle Like

(NF9) Artificial neutrino sources

(NF10) Neutrino detectors

Further reading (e.g., reference for existing TDR, reference paper, etc.)

[1A] M. Titov, arXiv:1308.3047 [physics.ins-det] (2013)

[2A] A. Bondar et al. NIM A 556, 273 (2006)

[3A] G. Bressi et al, NIM A310, 613 (1991)

[4A] J.G. Kim et al., arXiv: 0204033 [hep-ex] (2002)

[1B] D. González-Díaz, ‘A High Pressure TPC for the DUNE Near Detector’ talk at 10th Symposium on Large TPCs for low-energy rare event detection, 16-Dec-2022.

[2B] A. Buzulutskov et al., Astrop. Phys 103(2018)29;

[3B] C. A. O. Henriques, P. Amedo, J. M. R. Teixeira, DGD et al., ‘Neutral Bremsstrahlung emission in xenon unveiled’, accepted for publication in Phys. Rev. X.

[4B] P. Amedo, ‘Neutral Bremsstrahlung in Time Projection Chambers’, talk at LIDINE2021, 16-Sep-2022; P. Amedo, D. González-Díaz, B. J. P. Jones, JINST 17(2022)C02017.

[5B] E. Borisova et al., EPL(2022), <https://doi.org/10.1209/0295-5075/ac4c03>.

[1C] I. Giomataris et al., A novel large-volume spherical detector with proportional amplification read-out, J. Instrum. 3, P09007 (2008).

[2C] G. Gerbier et al., NEWS : a new spherical gas detector for very low mass WIMP detection, arXiv:1401.7902 [astro-ph.IM] (2004).

LOI References:

[1] Ben Jones, Diego Gonzalez Diaz, “Scintillating and Quenched Gas Mixtures for HPGTPCs”, [SNOWMASS21-IF8_IF5-NF10_NF0_Ben_Jones-070](#).

[2] Guillaume Giroux, “Search for Low Mass WIMPs with Spherical Proportional Counters”, [SNOWMASS21-CF1_CF0-IF8_IF0_Guillaume_Giroux-085](#).

[3] D. Caratelli, A. Fava, J. Zettlemoyer, “Electron multiplication in liquid argon TPC detectors for low energy rare event physics”, [SNOWMASS21-IF8_IF0-NF0_NF0-016](#).